Estimating Short-Circuit Capacity Using Measurements of Capacitor Switching Operations

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Abstract—**Short-circuit capacity (SCC) is fundamental to power system planning and expansion studies. Yet, despite accurate calculations from short circuit analysis programs, the calculated SCC values are rarely confirmed with real-world observations. This paper introduces a novel method to estimate SCC by utilizing waveform data captured by power quality monitors at transmission substations with capacitor banks. It defines the foundational assumptions and develops the necessary circuit equations for accurate SCC estimation. Through three application cases, the method's effectiveness and practicality are demonstrated, validating theoretical SCC values, and providing significant insights into grid strength variations over time caused by operational changes.**

Index Terms—**Short-circuit capacity, capacitor banks, short circuit analysis program, reactive power change, voltage change**

I. INTRODUCTION

Short-circuit capacity (SCC), also referred to as short-circuit level, available short-circuit current, and available short-circuit power, is a fundamental parameter in the planning and expansion of power systems. It is also crucial for designing and coordinating protective relaying systems, as well as for determining equipment ratings. SCC represents the maximum available current or power that a synchronous generator can theoretically supply to a bolted symmetrical short circuit at its terminals under steady-state conditions. Traditionally, SCC serves as a key indicator to assess the strength or 'stiffness' of a bus or system.

In recent years, the widespread integration of inverter-based generation resources, such as wind and solar farms, into the power grid has heightened the need for precise computation of the short circuit ratio (SCR). Various definitions for SCR, such as composite [1], weighted [2], and equivalent [3], have been proposed and utilized. However, regardless of the SCR definition used, a basic requirement of the calculation is the knowledge of SCC on the bus where new-generation interconnections are envisaged. This necessity highlights the critical importance of accurately determining SCC as it directly impacts the SCR calculation and, consequently, influences the evaluation of grid stability and the capacity for integrating renewable energy sources effectively.

In utility planning practice, SCC has been determined manually for simple circuits or using short circuit programs for large circuits. Unfortunately, validating the calculated SCC against the real-world fault current is rarely carried out. Bolted three-phase (balanced) fault currents are infrequent, and it is impractical to expect one to happen at the bus of interest. For this reason, empirical SCC is largely not available.

A recent work, reported in [4, 5], proposes estimating SCC using measurements obtained from phasor measurement units (PMUs), also known as synchrophasors. The estimation problem is formulated as a problem of estimating Thevenin equivalent impedance. The impedance is estimated using a robust least squares approach, taking PMU measurement uncertainties into account. A second-order cone programming technique is then employed to solve the least squares problem. This proposed method has shown promise in their specific PMU applications.

Contrary to the approach that relies on PMU data, this paper proposes estimating SCC using waveform data collected from power quality monitors, which are commonly installed at transmission switchyards for monitoring shunt capacitor banks (SCBs). This paper outlines the foundational assumptions and formulates circuit equations necessary for determining the capacity estimate through the analysis of capacitor switching data. It will be shown that the proposed estimation method works with measurement data of capacitor energizing and de-energizing operations. Subsequently, the paper presents real-world data collected from transmission-level SCB operations within the service territory of the Tennessee Valley Authority (TVA) and applies this data to the estimation process.

This paper demonstrates the utility of the proposed approach through three application cases, illustrating its effectiveness in estimating empirical SCCs and providing insights into grid strength variations over time due to operational shifts. Additionally, a comparative analysis juxtaposes empirically determined SCCs with those generated by a short-circuit analysis program, offering further validation of the method's accuracy and real-world applicability.

II. TRANSMISSION NETWORK AND DATA SOURCES

This section provides an overview of a typical transmission network setting in which SCBs are operational. It details the conventional layout of a transmission substation, pinpointing the locations of power quality meters, differential protection relays, and capacitor banks. Additionally, it includes a description of the waveform data collected from PQMs, which will serve as the basis for estimating empirical SCC.

A. Transmission Network: TVA

TVA is a generator and transmission owner and operator serving portions of seven states in the Southeastern United States as shown in Figure 1. The service area encompasses over 80,000 square miles and includes over 16,400 miles of transmission lines connecting over 500 substations. A significant majority of the transmission system is constructed and operated at 161 kV with a 500 kV backbone supporting the system.

TVA utilizes SCBs along with shunt reactor banks and 500 kV/161 kV intertie banks equipped with on-load load-tap-changers to regulate the voltage on the system. The SCBs are typically located at strategic 161 kV buses across the system to mitigate voltage violations against North American Electric Reliability Corporation (NERC) TPL-001-5.1 Transmission System Planning Performance Requirements. The SCBs are sized so as not to create a voltage step change larger than 2.0% when in normal (N) configuration and 2.5% when in N-1 configuration. There are approximately 100 stations across the transmission system having 300 SCBs comprised of nearly 12,000 individual capacitor units.

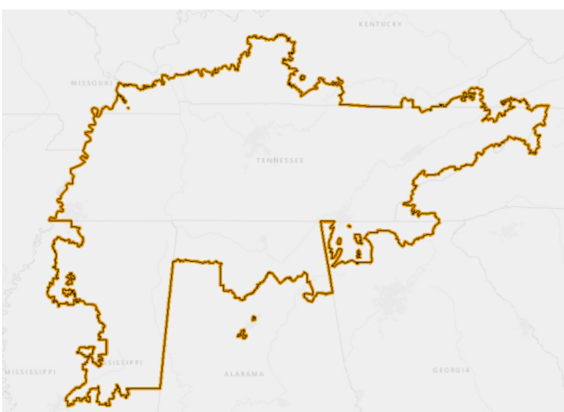

Figure 1 TVA service area

B. Typical Layout of TVA Substations and Capacitor Bank Arrangements

Figure 2 shows a typical layout of a station with SCBs which includes a breaker supplying a capacitor bank bus from which one or more capacitor banks are served via dedicated circuit switchers equipped with pre-insertion impedance switching to mitigate switching transients from capacitor energizations. Some stations also include inrush reactors ahead of the capacitor bank bus.

The older capacitor bank design utilizes series groups of parallel capacitor units which are each individually externally fused. The older design also utilizes Capacitive Coupling Voltage Transformers (CCVT) between the two middle series groups to provide voltage signals for protective relaying. The newer capacitor bank design utilizes parallel strings of series capacitor units which are not individually externally fused. The newer design has a voltage sensor set consisting of capacitor units, a voltage transformer, and resistors either at the common neutral tie (former uncompensated design) or in each phase individually just prior to the common neutral tie (present compensated design) to provide voltage signals for protective relaying.

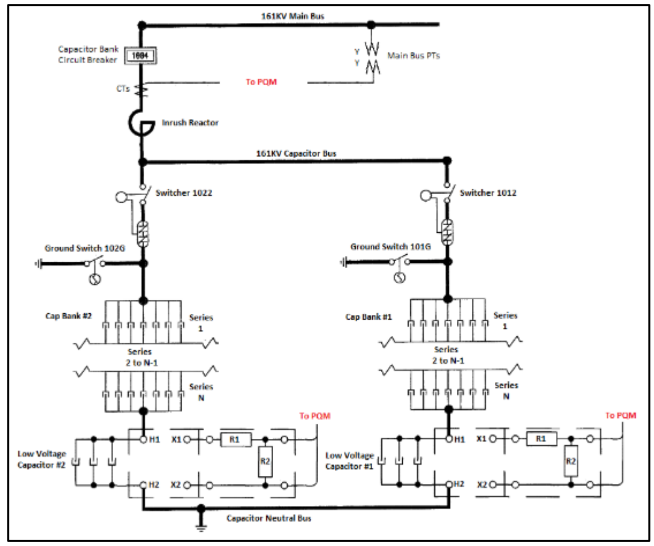

Figure 2 Typical layout of station with capacitor banks

C. Recording Capacitor Switching Operations

TVA has been installing Power Quality Monitors (PQM) and Digital Fault Recorders (DFR) at all substations with SCBs to obtain high resolution point-on-wave data of all capacitor bank operations. This includes the voltage signals from the main bus voltage transformers, the current signals from the capacitor bank circuit breaker, and the voltage signals from each capacitor bank protective relay. A waveform event record is taken every time a capacitor bank is energized or de-energized. Polling software downloads the event records in near-real time and the data files are processed into a central database for analysis.

D. Control Relays and Data Acquisition System

Capacitor banks are typically controlled automatically by a SCADA algorithm that utilizes both narrow band and wide band high and low voltage limits. A representative voltage signal typically from a voltage transformer on the main bus is used as the control. The capacitor banks are operated to keep the main bus voltage within the band limits of the controller. The controls alternate the operation of capacitor banks at a single station so that the service duty is balanced on all units. The controls utilize an override algorithm that detects hunting and prevents excessive operations. This feature was found to be necessary in weakened system configurations. Substations having capacitor banks typically have a capacitor bank operation at least once daily.

III. Method of Computing Empirical SCC

This section provides an overview of the definition of short circuit capacity, derives equations for estimating SCC, and demonstrates the application of the methods using a simple example.

A. Definition of Short Circuit Capacity

The fundamental concept of short circuit capacity is best illustrated using a synchronous generator under a bolted symmetrical fault condition, as depicted in Figure 3. Let the reactance of the generator immediately following the fault be represented with X_d''. The immediate period T_d'', lasting three to four cycles, is known as the sub-transient period. The fault current I_f'' flowing to the bolted fault during period T_d'' is computed as follows:

$$\mathbf{I_f''} = \frac{V_T \angle 0^{\circ}}{jX_d''} = -jI_f'' \tag{1}$$

where V_T is the rated terminal voltage. Fault current I_f'' represents the largest fault current that can be delivered by the generator during period T_d''.

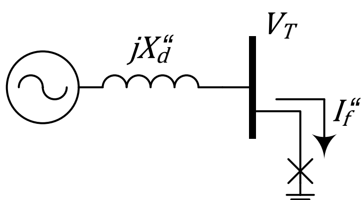

Figure 3 A synchronous generator with a symmetrical bolted fault

The corresponding short circuit capacity, SCC, is then calculated as follows:

$$\text{SCC} = |V_T(\mathbf{I_f''})^*| = V_T I_f'' = \frac{V_T^2}{X_d''}. \tag{2}$$

From (1) and (2), it is straightforward to interpret that the available short circuit current I_f'' and, thus, SCC correspond directly to the inverse of X_d''. Using a typical value of $X_d'' = 0.15$ pu, the available short circuit current and SCC are 6.67 of the generator's rated current and capacity, respectively. In other words, a 100 MW generator would provide an SCC of 667 MVA.

Let us now extend the definition of SCC to a transmission system bus, as illustrated in Figure 4. The transmission system, as seen from the source side of the bus, is represented by a Thevenin equivalent circuit, consisting of an ideal voltage source V_S behind reactance X_S.

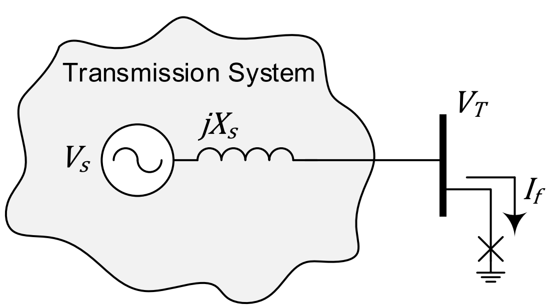

Figure 4 A transmission system bus with a bolted fault

Applying the same concept of SCC as used in the context of a synchronous generator, the SCC of the bus is calculated similarly,

$$\text{SCC} = |V_T(\mathbf{I_f})^*| = V_T I_f = \frac{V_T^2}{X_S} \tag{3}$$

where V_T is the bus nominal voltage and I_f is the fault current caused by a bolted and balanced short circuit at the bus. It is evident that a stiff bus, characterized by a low reactance X_S, will experience a high fault current and lead to a correspondingly high SCC value.

B. Using Capacitor Switching Operations to Estimate SCC

The SCC of a bus can be empirically determined when an unfortunate bolted balanced fault occurs at a bus, providing direct observation of the bus's electrical stiffness. However, without the occurrence of such a catastrophic event, it is still possible to empirically estimate the SCC at a bus, particularly where a capacitor bank is installed. This section outlines the basis for estimating the SCC through the analysis of capacitor switching operation events without needing an actual devastating fault to take place.

Consider a transmission bus equipped with a capacitor bank, as shown in Figure 5. The transmission system is represented by a Thevenin equivalent circuit, similar to the one shown in Figure 4. Let Q_{cap} be the reactive power contributed by the capacitor bank. The corresponding reactance of X_C is

$$X_C = \frac{V_T^2}{Q_{cap}}. \tag{4}$$

Further, let $V_{T,0}$ be the bus voltage when the capacitor is not in service. Thus, voltage $V_{T,0}$ equals V_S,

$$V_{T,0} = V_S. \tag{5}$$

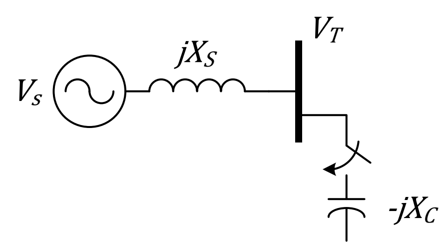

Figure 5 A capacitor switching operation for estimating SCC

The steady-state voltage increase ΔV when the capacitor is in service can be computed as follows,

$$\Delta V = V_{T,C} - V_{T,0}, \tag{6}$$

where $V_{T,C}$ is the bus voltage when the capacitor is in service. Using the circuit shown in Figure 5, $V_{T,C}$ is computed as:

$$V_{T,C} = \frac{-jX_C}{jX_S - jX_C} V_S \tag{7}$$

Using the bus voltages analyzed in (5) and (7), the steady-state voltage increase (6) can be expressed as follows,

$$\Delta V = \frac{-jX_C}{jX_S - jX_C} V_S - V_S. \tag{8}$$

Rewriting (8) in per-unit of V_S and assuming $X_S \ll X_C$, the per-unit steady-state increase ΔV_{pu} is

$$\Delta V_{\text{pu}} = \frac{\Delta V}{V_S} = \frac{-jX_C}{jX_S - jX_C} - 1 \cong \frac{X_S}{X_C}. \tag{9}$$

It should be emphasized that (9) generally holds true because the system short circuit reactance X_S is much smaller than the reactance of a capacitor bank X_C. Additionally, should the capacitor be equipped with an inrush current limiting reactor having reactance X_L, the denominator of (9) becomes $X_C - X_L$.

Using (3) and (4), it is now possible to rewrite ΔV_{pu} in terms of SCC and Q_{cap}, as follows,

$$\Delta V_{\text{pu}} \cong \frac{X_S}{X_C} = \frac{Q_{cap}}{\text{SCC}}. \tag{10}$$

The empirical SCC observed at the capacitor bus can be estimated as follows,

$$\text{SCC} \cong \frac{Q_{cap}}{\Delta V_{\text{pu}}}. \tag{11}$$

This is a significant finding, indicating that SCC can be estimated simply from dividing the reactive power contributed by the capacitor bank with the per-unit steady-state voltage increase it causes. Although it is not explicitly derived above, (11) also applies under conditions where ΔV_{pu} represents a steady state voltage reduction when a capacitor bank is de-energized.

Furthermore, it is important to point out that (11) remains valid when multiple capacitors are already present on the same bus. In such scenarios, Q_{cap} represents the reactive power contributed by the capacitor being energized or de-energized. Consequently, the calculated SCC reflects the conditions with capacitors already in service.

C. *Implementation of SCC Estimation Method*

This section provides a general guideline for applying the SCC estimation method to a bus equipped with a capacitor bank. According to (11), it becomes evident that estimating SCC necessitates the estimation of Q_{cap} and ΔV_{pu} as well.

Assuming the placement of the PQ monitor follows the layout described in Section 2, the three-phase voltage and current measurements captured at the capacitor bus will be the data utilized for estimating the SCC. Let $v[n]$ and $i[n]$ represent the sampled instantaneous values of the voltage and current waveform, respectively, for a specific phase, i.e., the A-, B-, or C-phase. The total data length in terms of the number of sample points of $v[n]$ and $i[n]$ is denoted by N, while N_c specifies the sampling rate per cycle. Figure 6 shows $v[n]$ and $i[n]$ of all phases during energizing and de-energizing operations.

From the waveforms shown in Figure 6, it is apparent that the capacitor bank is equipped with pre-insertion impedance closing switches. Consequently, sample points immediately following the instant of energizing operation cannot be used to estimate voltage change and reactive power contribution. Instead, the first and last six cycles, corresponding to a duration of 0.1 s in a 60-Hz system, are used for estimation.

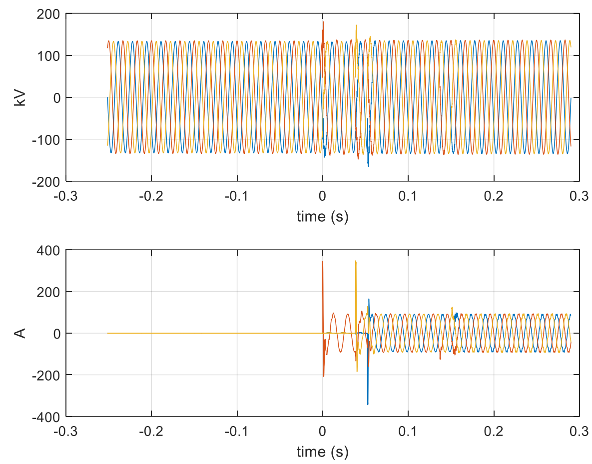

Figure 6 A capacitor switching operation for estimating SCC

Let the first and last six cycles of a sampled voltage and current waveforms be denoted by subscripts x and y, respectively. Thus, they are defined as follows,

$$\left.\begin{aligned} v_x &= v[n], \\ i_x &= i[n], \end{aligned}\right\} n = 1, 2, \dots, 6N_c \tag{12}$$

and

$$\left.\begin{aligned} v_y &= v[n], \\ i_y &= i[n], \end{aligned}\right\} n = N_e, N_e - 1, N_e - 2, \dots, N \tag{13}$$

where $N_e = N - 6N_c + 1$.

Do the following to estimate SCC at the bus where the capacitor is present:

1. Calculate the voltage phasors of v_x and v_y: $\mathbf{V_x} = V_x\angle\theta_x$; $\mathbf{V_y} = V_y\angle\theta_y$;
2. Calculate the current phasors of i_x and i_y: $\mathbf{I_x} = I_x\angle\phi_x$; $\mathbf{I_y} = I_y\angle\phi_y$;
3. Calculate their corresponding complex power: $\mathbf{S_x} = \boldsymbol{V_x I_x^*}$ and $\mathbf{S_y} = \boldsymbol{V_y I_y^*}$

The steady-state voltage change, ΔV_{pu}, i.e, either increase or decrease, is computed as follows:

$$\Delta V_{\text{pu}} = \frac{V_y - V_x}{V_{base}} \tag{14}$$

where V_{base} is the nominal bus voltage or another preferred nominal voltage. For an energizing operation, ΔV_{pu} is positive, while the opposite is true for a de-energizing operation.

The reactive power contributed by the capacitor bank is computed as follows,

$$\Delta\mathbf{S} = |\mathbf{S_y} - \mathbf{S_x}| = P_{cap} + jQ_{cap} \tag{15}$$

where P_{cap} and Q_{cap} are positive-valued real and reactive power contributed to the grid by the capacitor being energized. Finally, per-phase SCC is obtained by applying (11).

The procedure described above was applied to 11 capacitor switching events, captured by a power quality monitor installed on a 161-kV Beemount capacitor bus. This bus has four 18-Mvar capacitors. Using (14), voltage increases (positive values) and decreases (negative values), ΔV_{pu}, associated with capacitor energizing and de-energizing operation are shown in Figure 7. As expected, these values, in absolute terms, remain below 2%. Similarly, per-phase reactive power contributed by the capacitor to the grid or removed from the grid, Q_{cap}, as computed using (15), is depicted in Figure 8. Notice that these values are set to positive according to (11) and, as expected, they correspond closely to the rated reactive power of the capacitors. Although not shown, P_{cap} should be a small number representing real power losses of the capacitor bank.

The per-phase estimated SCC obtained using capacitor switching operation data is shown in Figure 9. The negative values correspond to estimates obtained using de-energizing operation data while the positive values using energizing operation data. It is evident that the per-phase SCC estimates are consistent between phases and over the 11 switching events. For additional clarity, the estimates may be plotted in absolute values as shown in Figure 10. It is clear that they occupy a tight band between 510 and 560 MVA with a mean value of 533 MVA.

These SCC estimates closely match with the SCC obtained from a short circuit computer modeling program. The Thevenin equivalent reactance at Beemount, with all ties closed, is found to be 6.47% on a 161 kV, 100 MVA base. Therefore, the theoretical SCC is 1546 MVA or 515 MVA on a per-phase basis. This validation provides additional confidence in using the above estimation method.

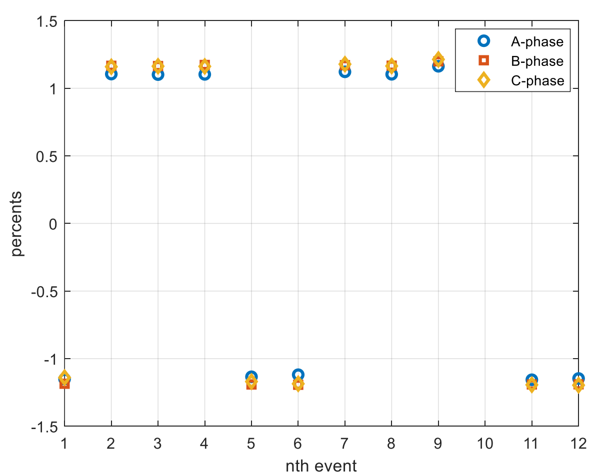

Figure 7 Voltage changes in percents associated with capacitor switching operations.

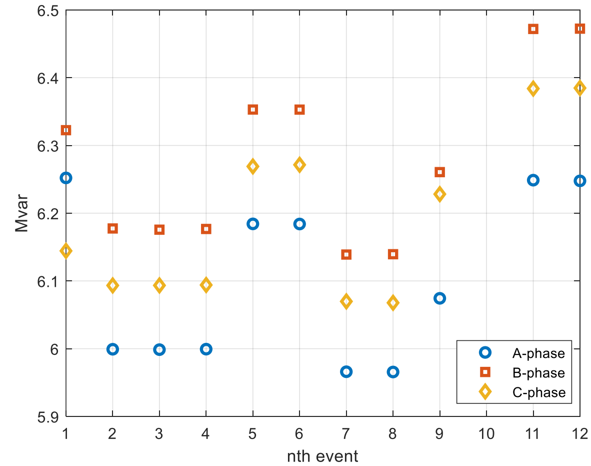

Figure 8 Reactive power in absolute value contributed to the grid or removed from the grid.

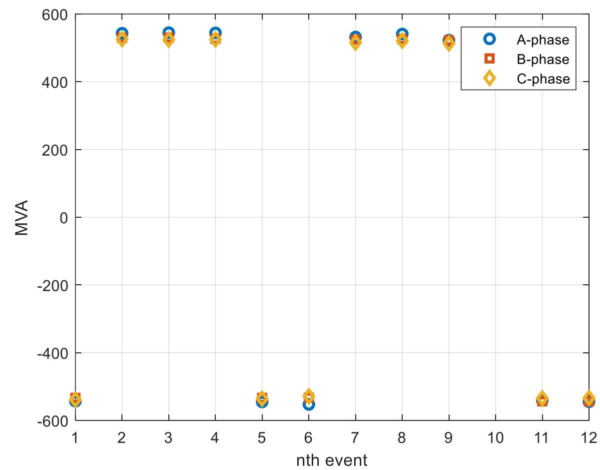

Figure 9 Per-phase estimated SCC of a substation where the capacitors are located.

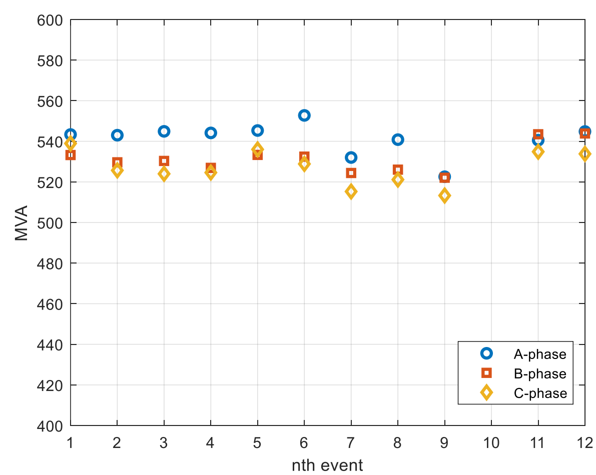

Figure 10 Per-phase estimated SCC in absolute values.

IV. Application Cases

In the subsequent section, three application cases are presented to illustrate the effectiveness and practicality of the proposed method for estimating empirical SCCs. These cases not only validate the expected SCCs obtained from manual short circuit analysis but also yield deeper insights into the variations in grid strength over time due to operational changes.

A. *Short-Circuit Capacity Over Time: Cooper*

The short-circuit capacity can vary over time due to several factors, including temporary changes in the operational status of generation and transmission lines, as well as the addition or retirement of generation assets. Gaining an understanding of how SCC varies over time is crucial, especially for the timely updating of protective relay settings.

Consider a 161-kV transmission substation, named Cooper, which is equipped with three 81-Mvar capacitor banks. With all nearby generation out of service, the three-phase solid fault at Cooper's capacitor bus calculated by a short-circuit computer program is 21 kA. Consequently, the corresponding SCC is 5856 MVA or 1952 MVA on a per-phase basis.

Power quality data collected from March 1 to June 30 is used to estimate the SCC and examine its variation over time. During this three-month period, there were 442 capacitor switching events out of a total 782 events observed. Using the analysis outlined in Section III, the estimated reactive power contributed to, or withdrawn from, the grid by the capacitor bank during each switching operation is shown in Figure 11. The analysis reveals that the estimates are bounded between 28 and 30 Mvar, with a mean and standard deviation of 28.92 and 0.61 Mvar, respectively. These estimates match well with the rated capacitor size of 27 Mvar/phase.

The empirical SCC over time at Cooper's bus is shown in Figure 12. It is interesting to note that the SCC estimates hover between 1750 and 2000 MVA/phase over the period of 3 months. These estimates are well within the expected SCC of 1952 MVA/phase.

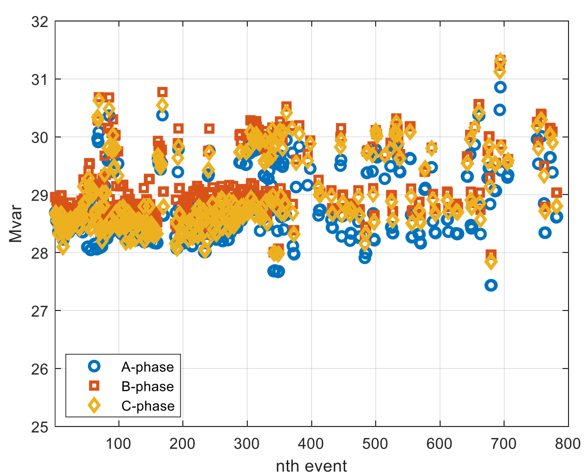

Figure 11 Cooper's reactive power on a per-phase basis contributed to or removed from the grid.

It is interesting to point out that the SCC on March 17 and 18 dropped significantly, reaching lows of 1508 MVA on the C-phase. This decrease was caused by the opening of three 161-kV transmission lines. A separate offline analysis was conducted using computer modeling software to simulate these line outages for validating the March 17 event. The computed SCC was found to be 5477 MVA. The corresponding empirical SCCs for the A-, B-, and C-phases were 1671, 1784, and 1711 MVA, respectively, totaling 5166 MVA. Consequently, the mismatch between the computed and empirical SCC is only 5.67%.

Additional validation was conducted for an event on March 27. The SCC computed by a short-circuit program was 6447 MVA, while the empirical SCC for all three phases combined was 6191 MVA. The mismatch between them is 3.97%. These two validation cases substantiate the accuracy of the proposed method.

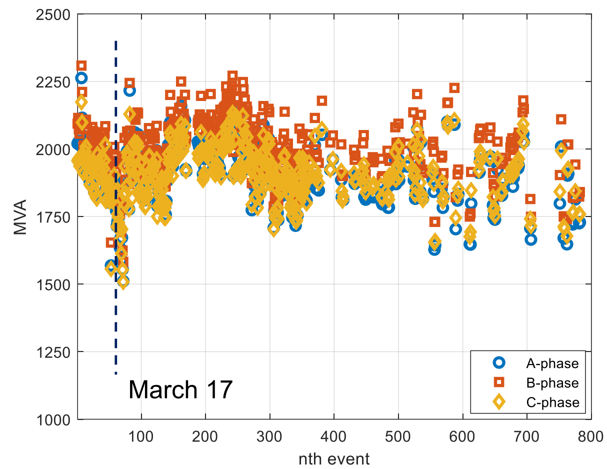

Figure 12 Cooper's per-phase estimated SCC between March 1 and June 30.

B. *Short-Circuit Capacity Over Time: Coffee*

A second application case is provided below to demonstrate the variation in SCC over time. A 161-kV transmission substation, called Coffee, has four 48-Mvar capacitor banks. The three-phase bolted fault current computed using a short-circuit program is 8.325 kA. It corresponds to an SCC of 2321 MVA or 773 MVA/phase.

A power quality monitor on the capacitor bus recorded 224 events between June 1 and June 30, of which 139 are associated with capacitor switching operations. These events are utilized to estimate the SCC. Figure 13 shows the estimated reactive power contribution by the Coffee capacitor bank during each switching operation. The mean and standard deviation of the reactive power are determined to be 17 Mvar per phase and 1.33 Mvar per phase, respectively, which align with the rated reactive power of the capacitors, i.e., 48/3 = 16 Mvar per phase.

The estimated SCC over the 30-day period is shown in Figure 14. Interestingly, during the first and last ten days of the period, the SCC at Coffee was 795 MVA/phase. This value closely aligns with the value computed by the short circuit analysis program, i.e., 773 MVA/phase. Conversely, between June 10 and 21, the SCC increased to 940 MVA/phase, due to an additional energized line. A simulation of the June-10 event using computer modeling software revealed a SCC of 3164

MVA, while the associated empirical SCC being 3098 MVA. Therefore, the discrepancy is only 2.09%.

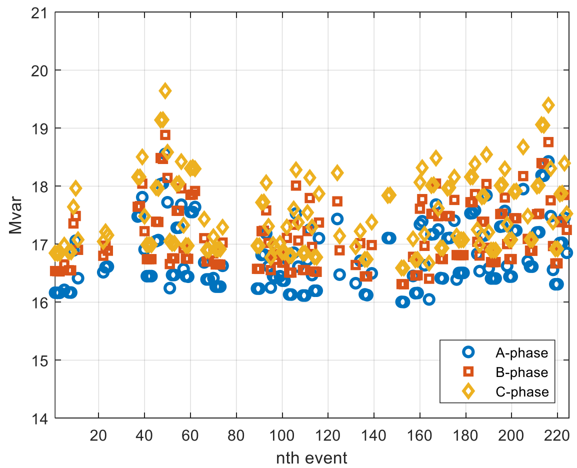

Figure 13 Coffee reactive power on a per-phase basis contributed to or removed from the grid.

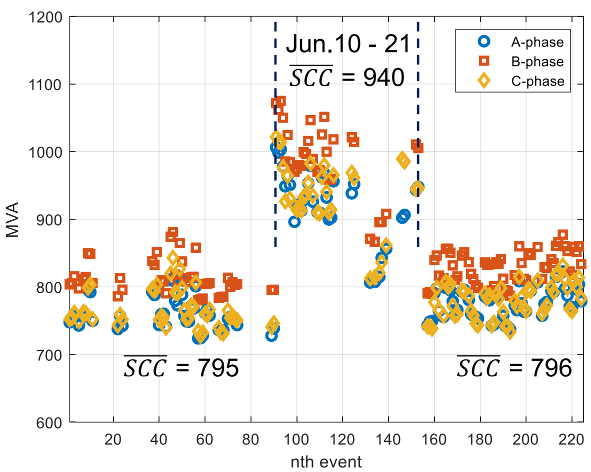

Figure 14 Coffee's per-phase estimated SCC between June 1 and June 30.

C. Short-Circuit Capacity with Line Outage: Polsky

This application case illustrates the variation of SCC over time and demonstrates its utility in providing insights into grid strength under line outage conditions.

A 161-kV transmission substation, called Polsky, is equipped with six 18-Mvar capacitor banks. A power quality monitor at Polsky's capacitor bus captured 33 events between Feb. 1 and 29, of which, 19 are associated with capacitor switching operations. As shown in Figure 15, the average estimated reactive power contribution from each switching operation is 6.38 Mvar with a standard deviation of 0.17 Mvar. This estimate closely matches with the rated value of the capacitor bank, i.e., 6 Mvar/phase.

During the observation period, the empirical SCC ranged between 525 and 600 MVA (see Figure 16), with two notable exceptions occurring on February 6 - Events 9 and 10. Event 9 involved capacitor energizing, while Event 10, occurring six minutes later, involved capacitor de-energizing. Both events recorded an SCC of 225 to 245 MVA/phase, significantly lower than the observed range. This decrease in SCC can be attributed to a line being open. A line outage simulation for these two events was conducted. The computed SCC is 664 MVA, while the empirical SCC is 705 MVA. Thus, the mismatch is only 6.25%.

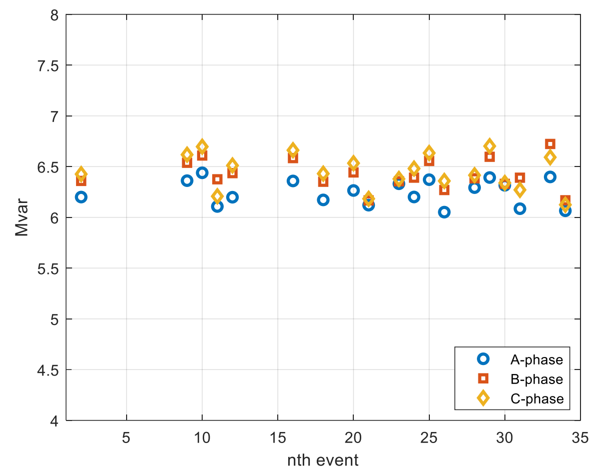

Figure 15 Polsky reactive power on a per-phase basis contributed to or removed from the grid by the capacitor.

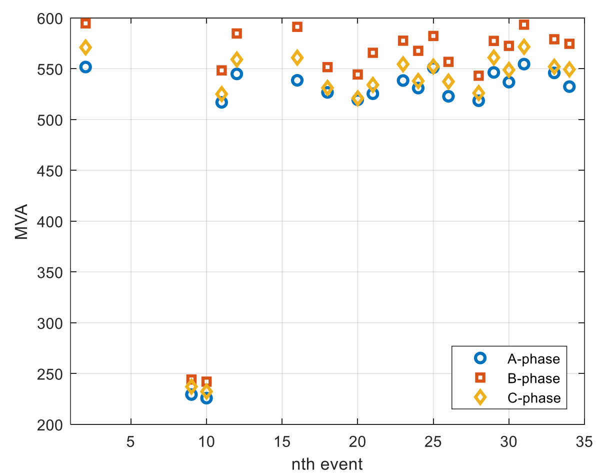

Figure 16 Polsky's per-phase estimated SCC between Feb 1 and Feb 29.

V. Conclusion

This paper proposes a practical and robust method for estimating the short-circuit capacity at a transmission substation using capacitor switching data. The accuracy of the SCC estimates is validated against values computed using a short-circuit analysis program. The effectiveness of the method is showcased through three application cases, which illustrate the variation in SCC over time due to operational changes or short-circuit faults upstream from the bus under study. In all validated cases, the SCC mismatches between the computed and empirical values were less than 10%, confirming the accuracy of the proposed method.

REFERENCES

1. C. Henderson, A. Egea-Alvarez, T. Kneupple, G. Yang, L. Xu, «Grid strength impedance metric: An alternative to SCR for evaluating system strength in converter dominated systems," *IEEE Trans. Power Delivery,* vol. 39, no. 1, pp. 386 – 395*,* Feb. 2024.
2. Y. Zhang, S-H Huang, J. Schmall, J. Conto, J. Billo, E. Rehman, "Evaluating system strength for large-scale wind plant integration," in *Proc. 2014 IEEE Power and Energy Society General Meeting,* National Harbor, MD, USA.
3. Chiyajo, H W, "Connection of wind farms to weak AC networks," CIGRE Technical Brochure 671, 2016.
4. H-Y Su, T-Y Liu, "Robust Thevenin equivalent parameter estimation for voltage stability assessment," in *IEEE Trans. Power Systems,* vol. 33, pp. 4637 – 4639, July 2018.
5. T. Ogane, Y. Nakachi, T. Nakajima, R. Yamaguchi, Y. Ota, S.C Verma, "PMU based short circuit capacity estimation and experimental verification on an analog simulator," *Proc. 2020 International Conference on Smart Grids and Energy Systems (SGES),* Nov. 2020, Perth Australia.